

Final Report

REGIONAL SEDIMENT ANALYSIS OF MISSISSIPPI RIVER SEDIMENT TRANSPORT AND HYDROGRAPHIC SURVEY DATA

by

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Background – Regional Sediment Management

Regional Sediment Management Concept

Stream systems in the United States respond to natural events and human activities. Over a long period dams, levees, diversion structures, and the straightening, widening, deepening, and clearing of channel systems have been employed to provide flood control, navigation, water supply, sediment management, irrigation, recreation, hydropower, mining, and fish and wildlife habitat improvement. The cumulative impacts of these activities, combined with watershed changes such as de-forestation, and urbanization have significantly disrupted the dynamic equilibrium of stream systems and the ecosystems within them. Channel erosion may cause serious on-site problems but it is increasingly recognized that the sediments generated channel instability are carried downstream through the system to cause sedimentation problems in flood control channels, destroy wetlands and lakes, adversely impact fish and wildlife habitats, degrade water quality, adversely impact infrastructure. In extreme cases, sedimentation itself may initiate further accelerated stream instabilities.

Historically, the focus of the Corps of Engineers' efforts has construction of large infrastructure projects for flood control and navigation. However, in the twenty-first century the focus is shifting to the design of channel systems on a regional basis, particularly with respect to sediment management. Progress is hampered because there is little published guidance for accomplishing effective regional sediment management and a shortage of reliable and comprehensive data sets with which to investigate and understand sediment sourcing, transfer and deposition processes at the regional scale. Sound data sets are required first to verify the existence of basin-wide linkages in the sediment transfer system, second to explore those linkages and third to identify how regional systems respond to river management and engineering to create problems that require costly and sometimes environmentally damaging solutions.

The long time-scales and complexity of channel response to past management and engineering preclude the use of many rivers for obtaining regional sediment data. However, within the continental USA, the Lower Mississippi River has benefited from a long and sustained data collection effort that may present the opportunity for analysis of sediment transfer and morphological change in response to engineering and management over a period of several decades.

Compilation of historical and contemporary data on sediment transport rates, sediment load and bed material particles sizes, channel morphology and engineering interventions (for example: re-alignments, cut-offs, bank stabilization and dike fields) can provide a data set of unparalleled value. Such data has the potential to support regional analysis of sediment transfer, morphological response and the identification of causal links between engineering and sediment problems at a variety of scales.

Previous Studies at University of Nottingham

Research on the management and morphological response of the Lower Mississippi River during the 20th century has been funded at the University of Nottingham under two previous research contracts. The first project was titled, 'Sediment Transport in the Lower Mississippi River' and dealt with compilation and initial analysis of all available sediment transport data from hydrometric gaging stations on the lower river. The second project was titled 'Morphodynamics of the Lower Mississippi River'. It carried forward the analyses initiated in the previous study to link sediment dynamics to morphological change and re-examining existing theories concerning trends and types of channel adjustment believed to be occurring in the lower river in response to past engineering and management.

Subsequent to the investigations funded by the Engineering research and Design Center (via the US Army Research Office (London)), research on the Lower Mississippi has continued at Nottingham under a postgraduate research scholarship awarded to Oliver Harmar. With the continued cooperation and active encouragement of staff at ERDC, the Lower Mississippi Division and the Vicksburg District, comprehensive databases of hydrologic, sediment transport and hydrometric survey data has been compiled and quality checked. Also, information on the location, nature and timing of engineering activities (construction of revetments, dike fields, cut-offs etc.) has been synthesized and recorded. Very considerable effort has been invested to transform the raw data in order make it usable in engineering-geomorphic assessments and analyses. To the best of our knowledge, the geomorphic databases developed at Nottingham represent the most complete and comprehensive record of engineering activities and morphological response in the Lower Mississippi River.

One important aspect of communicating the results of morphological investigations centers on the visualization of channel evolution and change. In this respect a further study was commissioned at Nottingham using internal funding. Steve Britnell, a masters student studying Geographical Information Systems, selected as his thesis topic investigation of a sub-reach of the Lower Mississippi River just upstream of the confluence with the Arkansas River. For his thesis research, he produced a video clips of channel change between 1992 and 2001 backed by spatial analysis of the impacts of change on key morphological parameters using neural networks and displayed in self-organizing maps.

The existence of this database allows the possibility of conducting an in-depth analysis that identifies causal links between altered sediment dynamics, morphological response and engineering activities in a very large river. Such research would usefully complement and extend the scope of similar work performed on smaller rivers. Development of geographical tools for visualization and spatial analysis of morphological change presents the opportunity for advanced treatment and display of the results.

Technical Report

Aims and Objectives

To establish the feasibility of using the databases in this way, a short preliminary study was performed. In this context, the objectives of this research effort reported here were to:

1. supply an inventory of available regional sediment and morphological data for the Lower Mississippi;
2. assess the potential of that data to support regional sediment analyses;
3. develop preliminary ideas on how sediment and morphological data might be used to visualize channel changes and develop improved understanding of river response to engineering and management at the local, reach and regional scales.

Morphodynamics of the Lower Mississippi River

Structure and Content of Existing Data set

The existing database is summarized in Table 1. The variety and consistency of data available is somewhat unique for such a large alluvial river and in time will allow a comprehensive geomorphic analysis to be undertaken. The electronic database is supported by a library of research publications on the geomorphic dynamics and engineering response of the Lower Mississippi River.

Table 1. A summary of the existing electronic database available at the University of Nottingham

| Base Data Sets | | Description | Time Interval | Spatial Interval | Data Coverage |
|---------------------------|-----------------------|---|--|---|--|
| Morphological | Comprehensive Surveys | Cross-sections at regular intervals | Years of survey: 1880, 1915, 1937, 1948, 1964, 1975, 1988, 1994 | Cross-sections at 300 – 400 metre intervals 15 – 50 points per cross-section | Cairo, IL to the Head of Passes, LA |
| | Annual Surveys | Cross-sections at regular intervals | Annually, 1992 – 2001 excluding 1998 | Cross-sections at 300 – 400 metre intervals 15 – 50 points per cross-section | Vicksburg District |
| | Seasonal Surveys | Collected along range lines | Every 1-4 weeks from 1998 to 2002 | Weekly surveys along the channel thalweg | Crossings within the New Orleans District |
| | Hourly Surveys | Multi-beam sonar datasets | 7-8 March 2001, 13 surveys over a 24 hour period | Spatially Distributed | Red Eye, Granada and Sardine crossings within the New Orleans District |
| Hydrological | Discharge | Discharge Records (cfs and cumecs) | From 1930s to 2002 Computed daily records Selected, infrequent measured records | Gauging stations at approximately 150 mile intervals | Cairo, IL to Head of Passes, LA |
| | Stage | Stage Records (ft and m, NGVD) | From 1930s to 2002 Records are daily | Gauging stations at approximately 50 mile intervals | Cairo, IL to Head of Passes, LA |
| Sediment Transport | | Suspended Sediment and Bed Material records | Continuous from mid 1970s to late 1990s Adhoc before mid 1970s | Gauging stations at approximately 150 mile intervals | Cairo, IL to Head of Passes, LA but mainly within the Vicksburg District |
| Aerial Photographs | | Digital Images (.tiff and .jpeg formats) | Survey undertaken during 1999 | Complete coverage | Vicksburg District |
| River Engineering records | | Records of dike and revetment construction and maintenance (.pdf) | N/A | Entry for each engineering feature | Memphis and Vicksburg Districts |
| Historic Planform Maps | | Scanned images from Elliot (1932) | Planform maps from 1765, 1830s, 1880s and 1920s | Continuous | Cairo, IL to Head of Passes, LA |

On-going Research using the Data set

Research currently underway at the University of Nottingham is part of an on-going programme of investigations concerned with elucidating spatial and temporal variations in the geomorphic stability of the Lower Mississippi River and assessing the extent to which the present planform pattern, longitudinal profile and cross-sectional geometry of the river result from response to river engineering and management.

The first phase of investigation was part of the research contract titled 'Morphodynamics of the Lower Mississippi River' and aimed to relate sediment dynamics to hydraulic changes in order to redress the geomorphic paradox noted by Biedenharn et al (2000). This stated that although there is evidence for an increase in stream power in the post cutoff period, no significant change in bed material size have been documented and further, previous investigators have inferred a reduction in the sediment loads on the Mississippi River this century. The detailed examination of sediment dynamics concluded general support for this decrease in total measured loads. However, most importantly, any trend within the transport of coarse (> 0.625 mm) load was poorly defined and thus, this apparent decrease may indeed mask an increase in geomorphologically bed material load. Thus, at a regional scale, the system may be responding back to an equilibrium state.

Ongoing morphological investigations at Nottingham are taking this research further by examining changes at several spatial and temporal scales. At the regional scale, historic hydrographic surveys allow changes in key morphological parameters to be examined at approximately decadal time intervals. However, to perform this type of analysis, it was first necessary to delineate the data sets into unique cross-sections and sort the data from the upstream direction. This pre-processing has been carried out for the 1948, 1964, 1975 and 1988 surveys and represented a considerable effort in terms of time and skills. Parameters could then be calculated and plotted for each cross-section. Changes in average depth, asymmetry, area and width-depth ratio are shown in Figure 1 for the processed data of the hydrographic survey undertaken in 1975. Several analytical techniques are now being used to investigate the spatial and temporal variation in morphological parameters as the system has responded to engineering and management.

A specific investigation into the regional sediment dynamics is focusing on key crossing reaches where sediments are stored, often as mid-channel bars. Morphological changes within pool reaches are not being considered for this investigation because local dynamics are generally more significant in controlling pool morphology than crossing morphology. Once identified, the sequence of changes at crossing reaches through time can be used to construct a more detailed model of response.

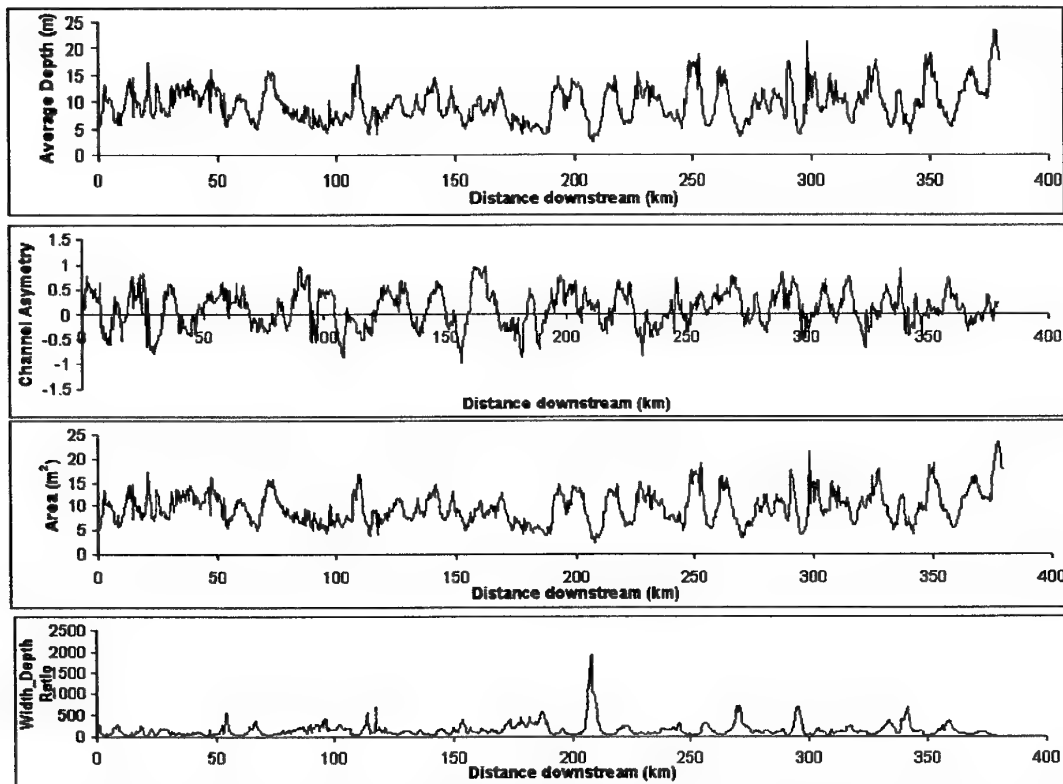


Figure 1. Key morphological change parameters for the 1975 hydrographic survey of the Vicksburg District

These regional analyses are being undertaken alongside more localised investigations using annual and shorter term datasets which highlight shorter term natural adjustments tendencies. This 'nested scale' approach is necessary to consider larger scale response to engineering within the context of natural adjustment dynamics.

Potential for Application of Lower Mississippi Dataset to Regional Sediment Management

Management History of the Lower Mississippi River

There is long history of management and engineering of the Lower Mississippi for flood defense, navigation and channel stabilization purposes. Activities include channel re-alignments and diversions, the building of levee, revetments and dikes, and dredging to remove bars and improve navigation. In addition, the river has been affected by extreme natural events such as the New Madrid earthquake and the great flood of 1927. Unusually, there is a complete record of significant events that provides the potential for matching morphological responses to engineering or natural causes and so provided an explanation of observed channel evolution. For example, Kesel (1988) provides an overview of historical impacts on the Lower Mississippi River, including a summary chart that is reproduced as Figure 2.

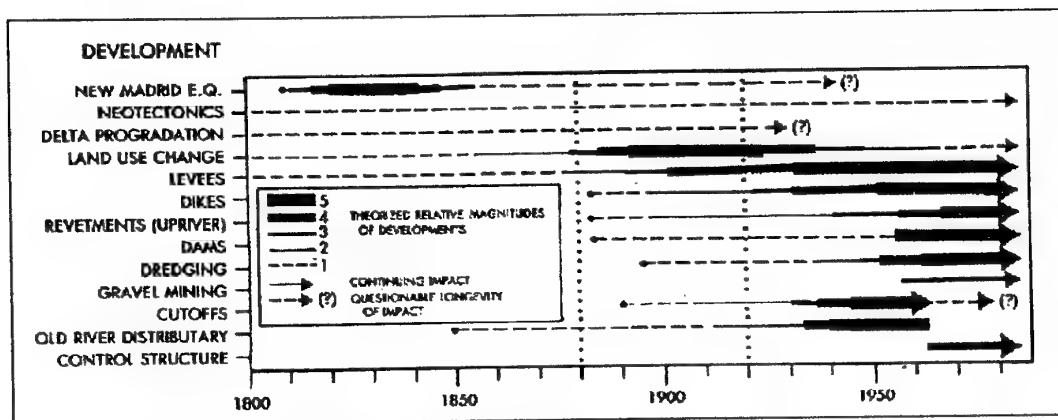


Figure 2. Overview of engineering activities and natural events impacting the Lower Mississippi River (After Kesel, 1988)

While a historical overview can be obtained from academic articles and papers, detailed accounts of works performed on the river are held by the US Army Corps of Engineers. These have been made available to the University of Nottingham by staff at the Vicksburg District and Lower Mississippi Division Offices. Record books give construction details and the date of construction of river works and subsequent modifications and maintenance operations pertaining to each scheme are listed in annually updated yearbooks. A sample record is shown in Figure 3 to illustrate the type of detailed information available for the Lower Mississippi River.

CATFISH POINT, MISS.-ARK. REVETMENT (573.0 L. - ARK)

Original Condition. Bank caving at this location threatened disruption of the existing favorable channel alignment into Cypress Bend on the opposite side of the river.

Original Project. Adopted in 1954 for bank protection to maintain a favorable channel alignment.

Summary of Work and Costs to 30 September

| FY | Linear Feet | | Construction Cost | Maintenance | | Remarks |
|------|-------------|--------|-------------------|-------------|------|------------------------------|
| | New | Reinf. | | Cost | Sqs. | |
| 1955 | 11,140 | | 1,478,822.71 | | | ACM & asph. U.B. paving |
| 1956 | 150 | | | 78,530.37 | | 150' dmstr. Ext., 330' repl. |
| | | | | 7,361.55 | | Minor repairs |
| 1957 | 1,515 | | 172,762.09 | | | Upstr. & dmstr. Ext. 175' |
| | | | | 202,003.84 | | repl., major repairs |
| | | | | 1,636.47 | | Minor repairs |
| 1958 | 145 | | 36,744.09 | | | 145' dmstr. Est. |
| | | | | 330,732.89 | | 140' repl., major repairs |

Figure 3. Sample entry listing construction details and subsequent modifications to a revetment at Catfish Point on the Lower Mississippi River

While the age, design and construction method of works is certainly important to understanding their morphological impacts and the response of the river at the regional scale, it is also vital to have good information on the layout of the works. This is particularly the case when river training is performed using not one but a whole series of different structures designed to interact in improving the channel with respect to flood control, navigation or stability. In the case of the Lower Mississippi, complete records of the layout of channel works are available in the form of channel improvement maps. Maps usually superimposed on an appropriate air photograph and are updated as necessary when new measures are introduced. A schemetised version of a typical reach improvement plan is shown in figure 4.

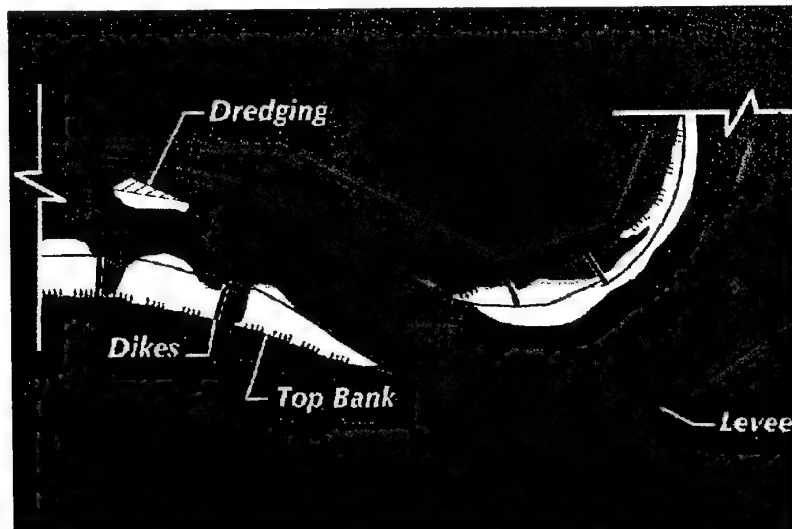


Figure 4. Schematic diagram of typical channel improvement map for the Lower Mississippi River

In addition to what may be termed 'conventional' river engineering, the cut-off program on the Lower Mississippi stands alone in terms of the scale and ambition of man's attempts to improve channel conveyance and navigation. During the period between the 1930s and the 1960s, a series of artificial and natural meander bend cut-offs took place (Figures 5 and 6). Morphological response of the river to the cut-off program remains a major academic research topic and there is no general consensus regarding the nature, distribution and duration of channel response (see next section for a review).

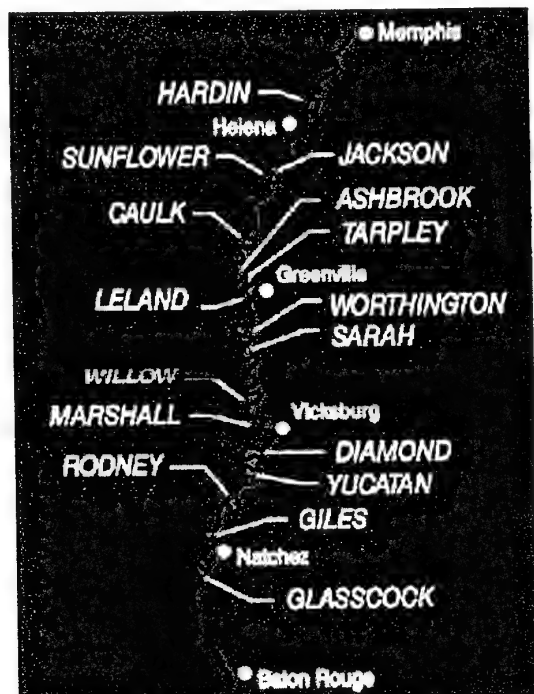


Figure 5. Mississippi River Cut-offs

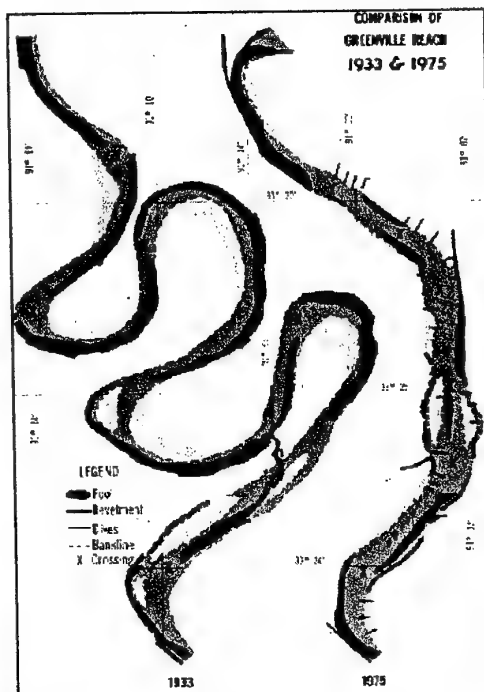


Figure 6. Greenville Reach Cut-offs

When coupled with the comprehensive database of morphological change, the record of channel shortening through re-alignments presents a unique opportunity for investigating the system-wide response of an alluvial river to large-scale engineering interventions. Such a study would usefully extend the scope of investigations of regional sediment management to include the largest river system in the US.

Current Morphological Stability Status

The current morphological stability status of the Lower Mississippi River has been investigated by Biedenharn (1995) through examination of specific gauge records at six key gaging stations in the post cutoff period. The proposed long term model of response (Figure 7) suggests a zone of degradation extending upstream of Arkansas City to Memphis and a zone of aggradation extending downstream of Arkansas City to Red River Landing. Thus, the model proposes that at a large spatial scale, the river is responding in the same manner as the response to a single cutoff outlined by Lane (1947).

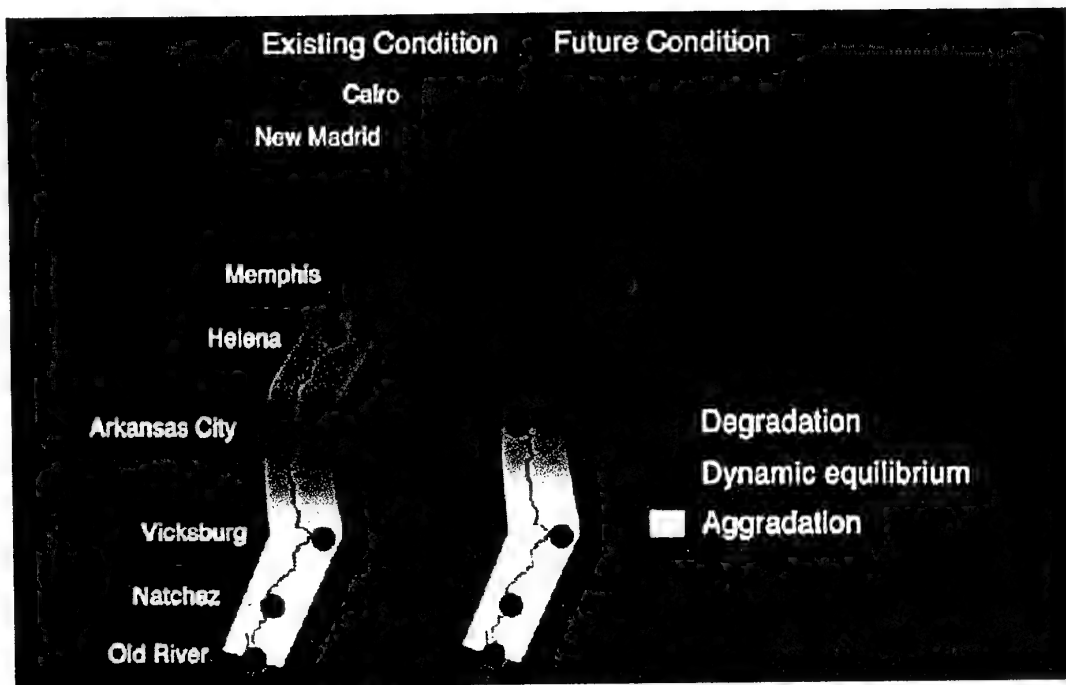


Figure 7. Proposed Model of Response

This model, although useful for conceptualising geomorphic response at the large scale, is almost certainly an over-simplification of morphological adjustments at the reach scale. For example, Smith and Winkley (1996) state how some reaches are experiencing local aggradation and the formation of mid-channel bars whereas other reaches are relatively stable morphologically. Hence, by undertaking analysis of detailed morphological data sets, adjustment tendencies at smaller spatial and temporal scales can be investigated to improve understanding of fluvial dynamics and related geomorphological response.

Linking River Engineering to Regional Geomorphic Response

The key to progress in understanding sediment dynamics and morphological responses at the regional scale lies in properly and accurately linking engineering actions to morphological reactions. Initially, links may be identified on the basis of spatial analyses and inferential statistics that show significant relationship between the timing and location of engineering works and morphological changes. However, this type of approach cannot provide the basis for improved sediment management at the regional scale because the links established are not necessarily causative.

A better approach to linking cause and effect rests on understanding the fluvial process-response system that operates in an alluvial river. This depends on accurate identification of sediment sources, transfer paths and sinks because it is the through the redistribution of sediment that morphological change occurs. In this respect a distinction should be drawn between short-term morphological responses – achieved through rapid transfer of relatively fine sediment moving as wash load; and longer-term response achieved through

the slower movement of relatively coarse, bed forming sediment moving as bed material load.

The investigators at Nottingham are fully aware of parallel studies of regional sediment management in small rivers being performed in the Coastal and Hydraulics Laboratory at ERDC in conjunction with Colorado State University. Their work, centered on understanding and modeling connectivity in the sediment transfer system, will provide a conceptual and practical blueprint to underpin analysis of the engineering-morphology database for the Lower Mississippi.

Visualizing channel response

The objective of this part of the study was to explore approaches to visualizing channel morphology and morphological changes and identify the most appropriate methods of visualizing morphological response to the impacts of natural events and human modifications on large alluvial rivers. This was addressed using 3 types of visualization of varying complexity and degree of abstraction, based on annual, geo-referenced hydrographic survey data for a selected sub-reach of the Mississippi River immediately upstream of its confluence with the Arkansas River.

The three visualizations feature two-dimensional maps of bathymetric change, which are relatively simple to produce, but slightly abstract and difficult to interpret, a 3-D temporal animation, which is more difficult to create but is the most realistic and easy for non-specialists to comprehend, and Kohonen Self-organising mapping nested within a virtual world, which is the most complex and abstract visualization.

The visualizations cannot be fully reproduced in a paper report, but have been supplied to Ms M Corcoran and Dr D S Biedenharn at the US Army Research and Development Center, Vicksburg on CD-ROM. In the remainder of this section of the final report, brief overviews of the visualizations are presented for completeness.

Visualization Reach

The work focused on a single reach, called the Arkansas reach, which extends from river mile 560 to river mile 605 (Figure 8). The base data come from annual surveys performed between 1992 and 2001 by the Vicksburg District, Corp of Engineers.

Bathymetric change

Bathymetric change is a traditional visualization method and can be used to reveal areas of a river channel that have aggraded or degraded between two time periods. The method used to produce such a map of difference is to subtract the digital elevation model of one year from the other. Digital elevation models (DEM) are powerful tools for visualizing landscapes, and can be defined as *an ordered array of numbers that represents the spatial distributions of elevations above an arbitrary datum in a landscape*. They have been used in the past to investigate river morphology.

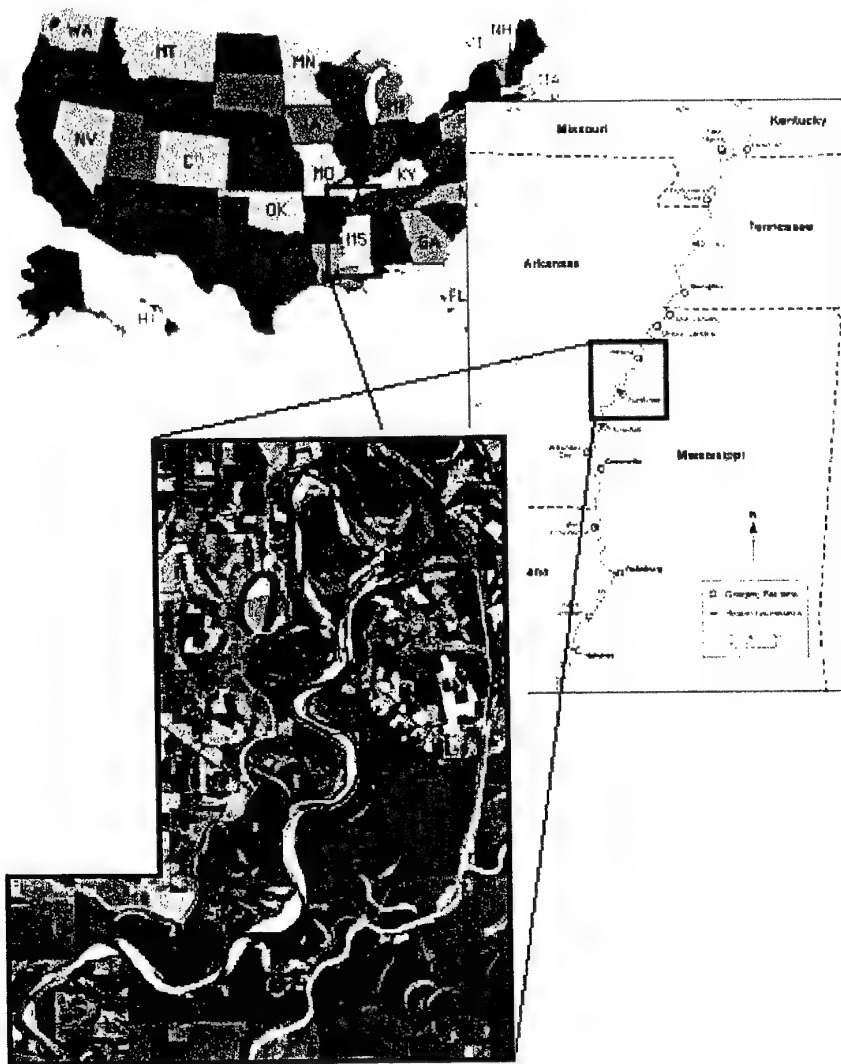


Figure 8. Location of the Arkansas reach, Mississippi River, USA

Temporal animation

An ordered series of graphics is an animated display, which has the ability to communicate large amounts of information in an instance to the user. Animation also has considerable potential to analyse and increase the understanding of multi-temporal data of complex dynamic systems such as river morphology. By employing the techniques of Delauney triangulation, realistic 3-dimensional views of the Arkansas reach can be produced. With little abstraction, an appropriate color scheme, and suitable transitions, a sophisticated animation can be created.

Fading techniques are required in the animation of morphological changes. Fade transition use a degree of interpolation to generate slides that give the user the impression of how the landform would develop over the allotted time period. This kind of evolution is well suited to river morphology, and can be just as effective when applied to yearly changes. Fade transitions are effective at giving an overview of channel change, where on the other hand, fly-through animation can give a fast detailed view of the data. These two techniques combined, provide a quick overview of the data that is vital in the decision making process. Animation presents the user the opportunity to make complex contextual analysis based on subtle changes in color, shape, location and size of landforms, in this respect it is ideal for visualizing river morphology.

Neural networks and the self-organizing map

Neural networks are advanced mathematical models that consist of a number of processing units that are arranged in layers and combined to form a network. Neural networks are in practice straightforward to use, and have distinct advantages over traditional physical models, which are often too complex, and data and resource hungry. The self-organizing map (SOM) is the most widely used neural network model, and the SOM developed by Kohonen is most commonly employed in morphological work. The main application of the SOM is in data mining, where it is mainly used to visualize complex data in an abstract 2-dimensional manner, essentially as an unsupervised clustering technique.

The SOM works through the processing units competing with each other to reveal patterns that exist in the data. The traditional SOM layout consists of an input layer and a competitive layer. The competitive units are connected to form a lattice with a topological neighborhood function, this when trained, signifies the primary pattern associated with each class. Training is preformed through the method of back propagation, which is where a pattern is presented to the network and subsequently determining which unit it is most represented by, then updating the winning unit and those around it. Labeling of the units is achieved through two stages. First, through observation of trial and error by presenting known patterns to the network, and noting the winning unit. The next step is confirmation, which is achieved by using constructed ideal patterns to test the initial labeling of the units. The data is often normalized onto a 0 to 1 scale, this improves accuracy, because the reference vectors then have the same dynamic range.

The SOM can be used to simplify morphological data into its component parts. This can be applied to the Arkansas reach data by describing channel shape based on a number of variables. Although the SOM has been used in the past as a visualization tool, it has often been deemed to be too basic and require improvement. A suitable output interface to a SOM would be a virtual world.

Virtual reality

Virtual environments are synthetic sensory experiences that offer a more interactive way of communicating abstract information to the user. Virtual environments are designed using the standard Virtual Reality Modelling Language or VRML for short. VRML coupled with a suitable browser such as Cosmo-player, provides a method of integrating GIS, virtual reality and the internet, and provides a cheap, powerful means of exploring and analysing geographical data to gain insights into the relationships between morphology, morphological change and attributes of the channel with respect, for example, to flood control, navigation or habitat provision.

Results

The full results (bathymetric change maps, animations and the Virtual World) are available on CD-ROMs supplied to the sponsors at ERDC. The bathymetric change maps are shown in Figure 9. An example of the appearance of the animation screen is shown in Figure 10. Typical output of self-organizing mapping within a virtual world is shown in Figure 11 to illustrate the form of the results.

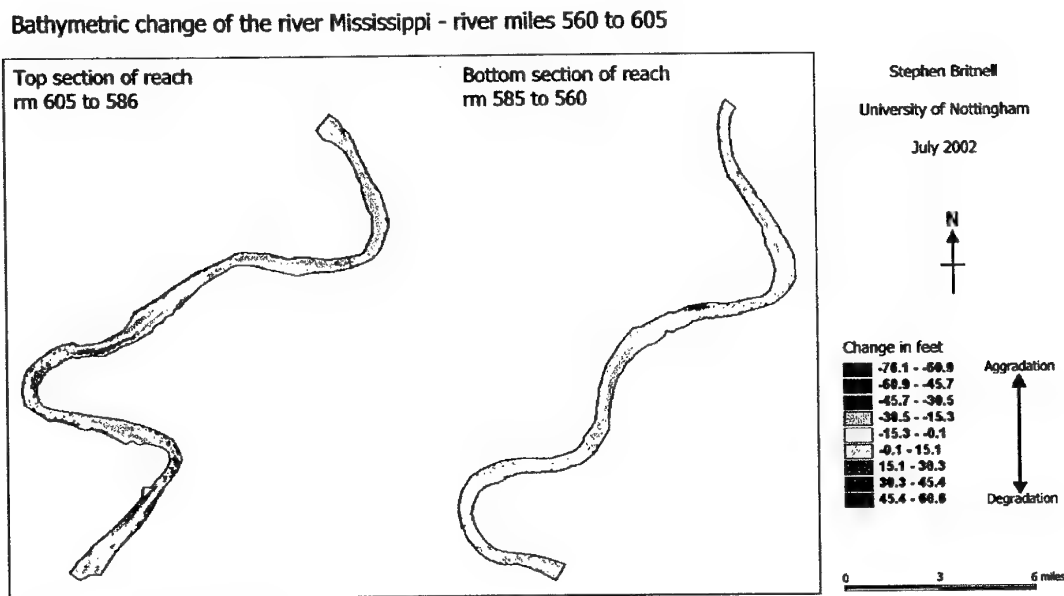


Figure 9. Bathymetric Change Maps

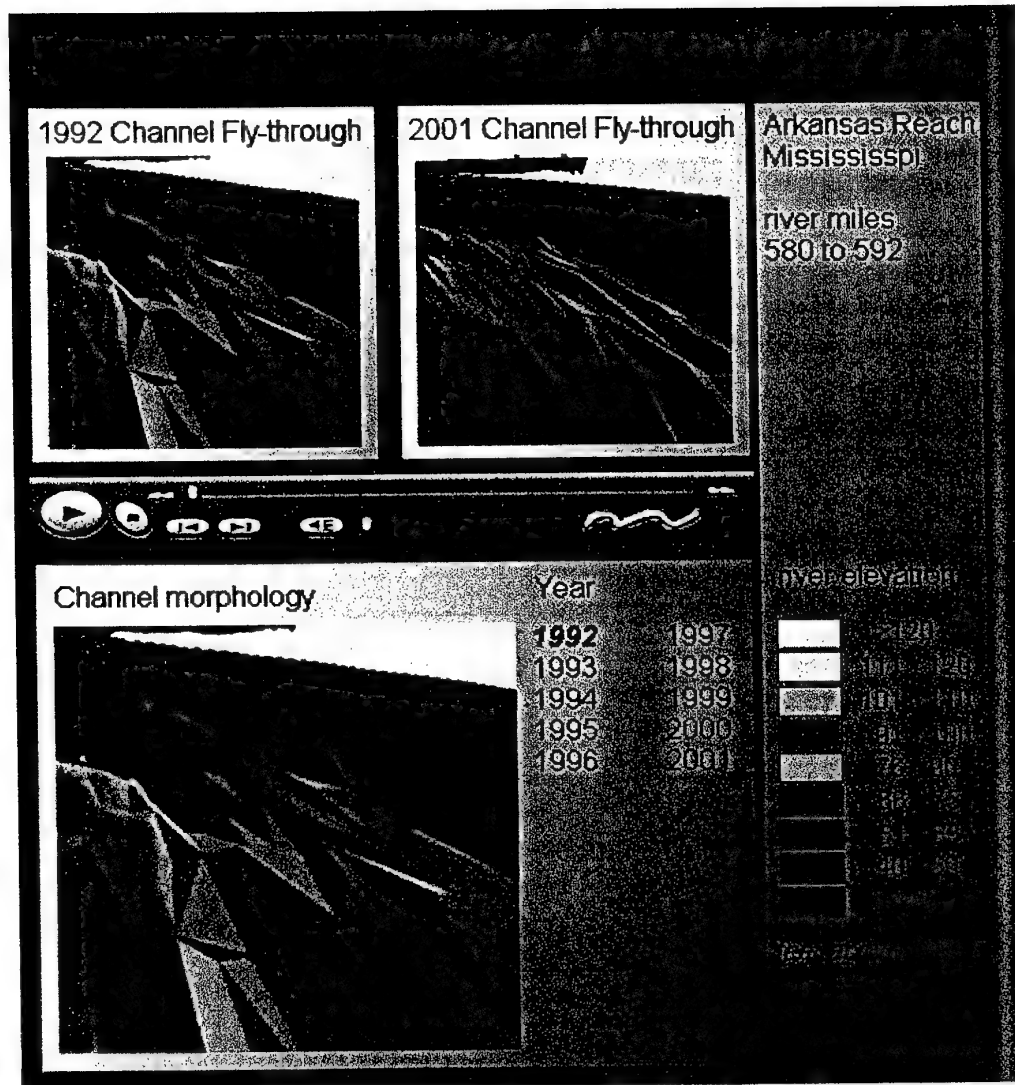


Figure 10. Appearance of animation screen for channel morphology

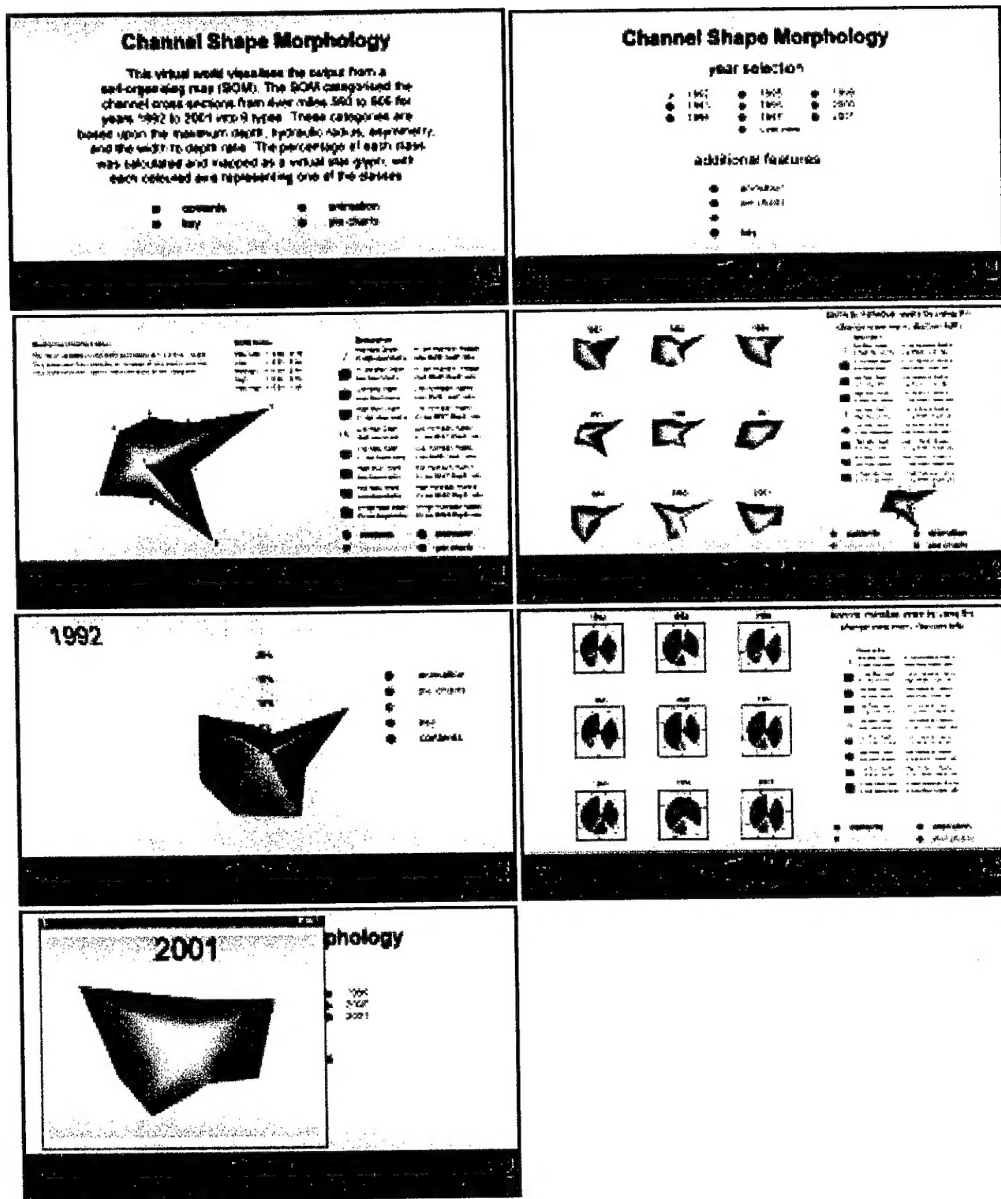


Figure 11. Virtual world contents

Conclusions

This exploratory study has revealed that there is not one type of visualisation that is best to visualise morphological change in large alluvial rivers, but that combining each of the visualisations strengths through the integrating power of a virtual world, or the web, is the most appropriate technique. The amalgamation of the easy interpretation of the bathymetric change, with the aesthetics of the animation, and effortless transition and

data exploration powers of the virtual world, gives a comprehensive view of temporal channel morphology.

Further work is required to determine how people interpret temporal data that is static, moving, and displayed in virtual worlds. Gauging how people understand visualisations will give guidance on how to develop and improve future work in this advancing area of GIS.

Conclusions

- Compilation of historical and contemporary data on sediment transport rates, sediment load and bed material particles sizes, channel morphology and engineering interventions (for example: re-alignments, cut-offs, bank stabilization and dike fields) has the potential to support regional analysis of sediment transfer, morphological response and the identification of causal links between engineering and sediment problems at a variety of scales.
- The database of hydrologic, sediment transport and hydrographic survey information for the Lower Mississippi River is sufficient to support in-depth analysis and identify causal links between engineering activities and geomorphological responses in this very large river.
- Work on linking morphological change to natural events and river engineering interventions on the Lower Mississippi River would usefully complement and extend the scope of similar research performed on smaller rivers.
- Development of geographical tools for visualization and spatial analysis of morphological change as illustrated in this preliminary study presents the opportunity for advanced treatment and display of the results of analyses of regional sediment impacts and morphological responses.

Further Research

Based on the results of this initial investigation further research is required to:

- Chronicle the history of morphological change in the Lower Mississippi during the modern era (post-1880) and differentiate styles of adjustment associated with evolution of the system and response to specific natural events and human interventions;
- Select key reaches displaying particular trends and types of morphological change that are clear and well-documented;
- Establish detailed histories of natural events, channel management practices and engineering works that have the potential to have triggered or driven morphological response in the selected reach;
- Use advanced forms of spatial data analysis and visualization (including animations and self-organized mapping in a virtual world) of the Mississippi River database to identify and display causal links between formative events and morphological responses.
- Consider the findings in the context of Regional Sediment Management to produce generalised findings of use to engineers and scientists and managers dealing with other large rivers in the continental USA.